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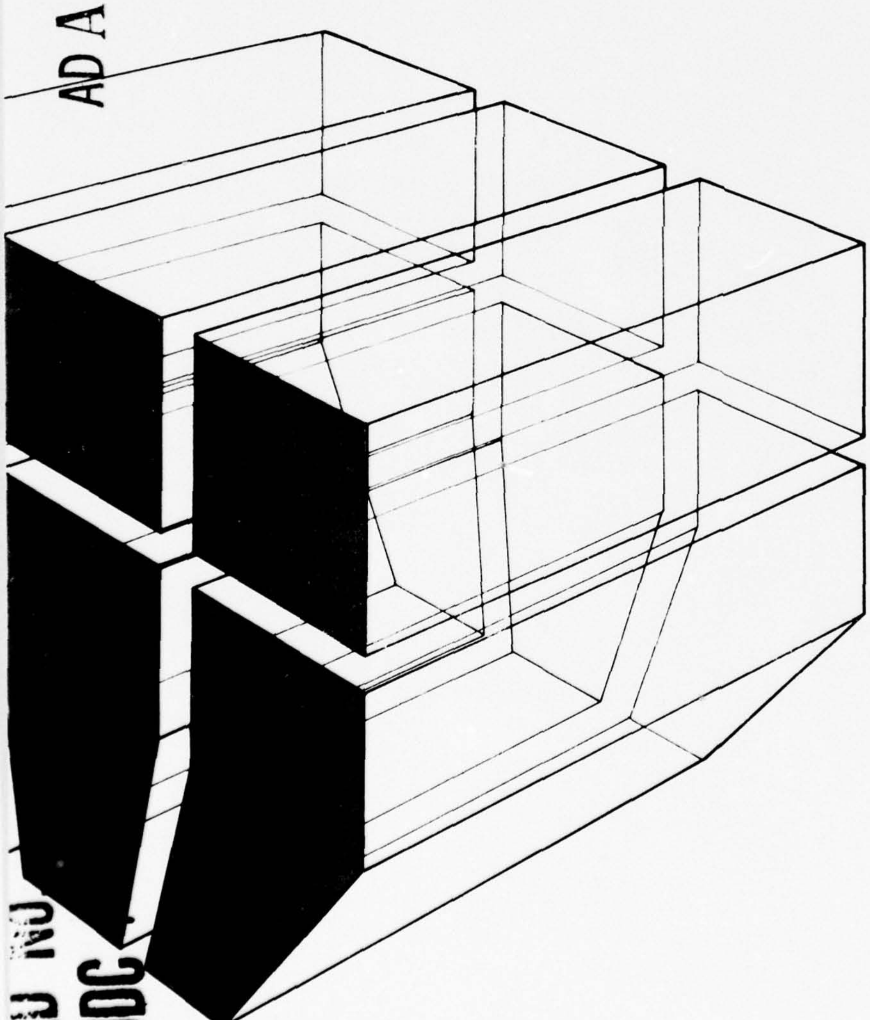
DESIGN FEATURES OF PACKAGE INCINERATOR SYSTEMS



by
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This report summarizes information collected in the early stages of a project to evaluate current small-scale solid waste incineration technologies for use at Army fixed facilities and installations. Information gathered through literature review, field observation, and contact with manufacturers and vendors is presented. Subjects covered include basic plant design requirements, site selection, waste receipt and handling, ash handling and disposal, instrumentation and controls, operation and maintenance, personnel facilities, safety, and → next page

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cont. pollution abatement. A technical description of each currently marketed package incinerator configuration (controlled air, rotary-kiln, basket-grate, and augered-bed combustor) is given.

Application of a comparable performance rating system shows that none of the four package incinerators currently available can be confidently recommended as a reliable, cost-effective method of handling solid waste generated at Army installations. A program of continued evaluation of currently operating plants coupled with field tests of candidate units on Army solid waste is encouraged.

FOREWORD

This report was prepared by the Energy Branch (EPE), Energy and Power Division (EP), of the U. S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Military Construction, Office of the Chief of Engineers (OCE). Work was conducted under RDT&E program 6.21.12A, Project 4A062103A891, "Environmental Quality for Construction and Operation of Military Facilities"; Task 03, "Facilities Pollution Control"; Work Unit 002, "Criteria for Pollution Control Facilities." The applicable QCR is 1.03.006(4). Mr. H. McCauley was the OCE Technical Monitor. Administrative support provided by Dr. D. J. Leverenz, Chief of EPE, and Mr. R. G. Donaghy, Chief of EP, is acknowledged.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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DESIGN FEATURES OF PACKAGE INCINERATOR SYSTEMS

1 INTRODUCTION

Background

Recently, there has been a major growth trend in the design, manufacture, and sale of smaller-scale solid waste incinerators. This reflects the broad swing from landfill disposal of putrescible trash and garbage to thermal processing systems, whose product is an essentially inert ash and residue which can be landfilled in an environmentally compatible manner. Bulk reduction of wastes through incineration can be as great as 98 percent, adding years to a landfill's functional life.

As greater constraints are placed on landfilling active wastes, installation waste disposal operations personnel will probably give increasing consideration to implementing incinerator systems. Small-scale incinerators having potential installation application are in the processing range of up to 19 MBtu/hr (20 GJ/hr), or approximately 1.12 tons/hr (1.02 t/hr) of waste having a heating value of 8500 Btu/lb (19.8 MJ/kg). Such incinerators are usually "package" or "modular" units predesigned, off-the-shelf, highway-shippable units which are generally procurable with a 6-month lead time. Because of their relatively low cost as compared to field-erected incinerators, these units have potential application on more than 75 percent of major Army installations in CONUS, where the average solid waste generation rate is approximately 41 tons/day (37.2 t/day) (5 day/week basis, Figure 1).

The major technical manual that provides instructions and information for the design of installation-scale incinerators does not reflect the accelerating technological changes of the past few years.[1] Cognizant of this, the Office of the Chief of Engineers (OCE) initiated an effort to evluate current installation-scale incinerator technologies and incorporate recommended system changes into updated technical manuals.

Objective

The objective of this investigation was to evaluate current small-scale solid waste incineration technologies.

[1] *Sanitary Engineering, Incinerators*, TM 5-814-4 (Department of the Army, May 1959).

Approach

The information contained in this report reflects activities carried out during the initial stages of the project: extensive literature review, field observation, and contact with manufacturers and vendors of package incineration equipment and systems. With the exception of the technical description of small-scale incinerators, which was obtained exclusively from field contacts and observations, information came largely from the literature review. A comparative performance rating system was applied to evaluate the potential of the four currently marketed package incinerator configurations.

Scope

This report presents information pertaining to the design and operation of package installation solid waste incinerator plants having a processing capacity ranging up to approximately 80 tons/day (72.6 t/day).

Mode of Technology Transfer

This report may be used by OCE to update TM 5-814-4, *Sanitary Engineering, Incinerators* and related documents, as appropriate.

2 BASIC DESIGN REQUIREMENTS

General

Incinerator capacity is based on heat release rate, not mass flow rate or throughput capacity of wastes. This section provides a method for determining plant capacity, operating schedule, and number and rating of incinerators for use in project development.

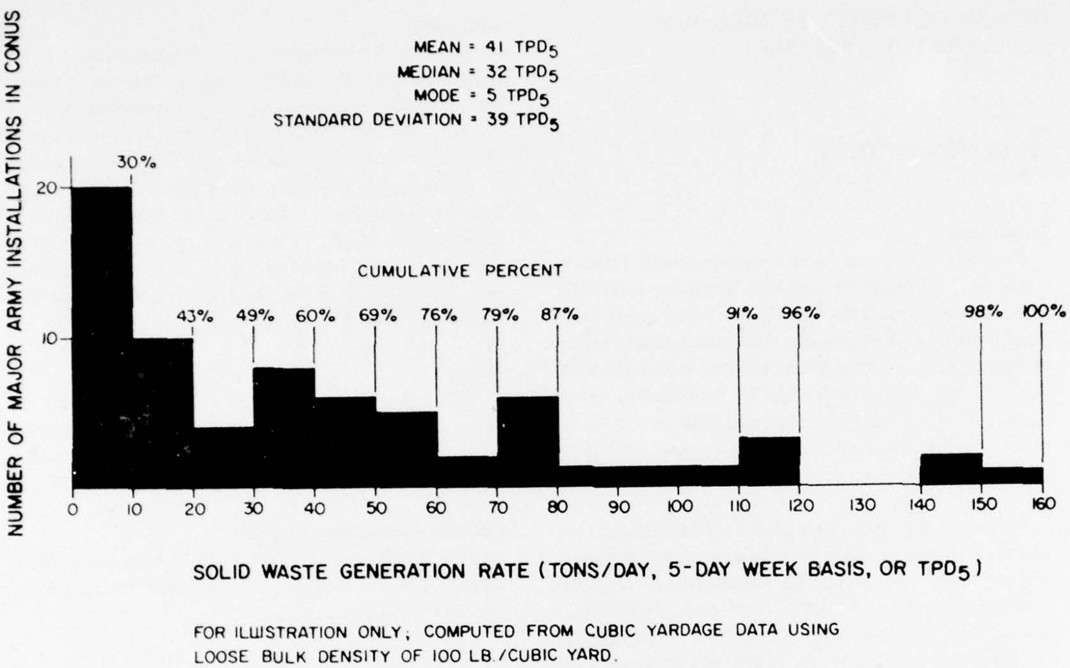
Classification of Wastes

Table 1 provides classification and source data for wates that can be processed in conventional package incinerators.

Types and Quantities of Waste

Identifying types and quantities of wastes is a critical stage in project development for a new small-scale incinerator plant and requires a careful and accurate survey. CERL Technical Report E-75 provides guidance for conducting a waste survey at an installation.[2] When a project enters the design stage, the designer is

[2] G. Schanche, L. Greep, and B. Donahue, *Installation Solid Waste Survey Guidelines*, Technical Report E-75/ADA018879 (U. S. Army Construction Engineering Research Laboratory, September 1975).



Computed from cubic yardage data using loose bulk density of 100 lb/cu yd.

Figure 1. *Distribution of solid waste generation rate at major Army installation in CONUS in FY75.*

usually required to resurvey the waste to confirm the design points obtained in the preliminary survey by installation personnel.

Computation of Incinerator Plant Design Capacity

Incinerator design capacity is a function of actual burning time after a preheat period. In package systems, the preheat period rarely exceeds 1 hour; hence an 8-hour shift usually provides 7 hours of effective burning time, with unit cool-down time provided after the end of the operating period. Package incinerators do not exceed capacities of 19.5 MBtu/hr (20.6 GJ/hr) of waste heat release rate; due to slagging potential, they are usually not operated continuously for more than 24 hours or at furnace temperatures greater than 1800°F (982°C). Capacity is chosen for 5 days/week operation when possible, leaving weekends available for extended operation in peak load processing and maintenance. Design capacity is given by Eq. 1:

$$\text{Design capacity} = \frac{1.25 \times H}{\text{burning hours/day}} \quad \text{[Eq 1]}$$

where:

H = heating value of waste stream (MBtu/day)

1.25 = factor allowance for contingency variations in generation rate and for load factor.

The factor H is derived by multiplying the generation rate (lb/day) by the heating value of the waste (Table 1).

The number of incinerators required can be determined from the number of burning hours/day. For example, if a waste survey shows 445.8 MBtu/day (470.3 GJ/day) of waste energy available, and operation is 7 hours/day, an incinerator rated at 79.6 MBtu/hr (83.9 GJ/hr) is required. However, the maximum available incinerator rating is 19.5 MBtu/hr (20.6 GJ/hr), so at

Table 1*
Classification and Source Data for Wastes Suitable for Incineration
(Adapted from *Incinerator Standards*, Incinerator Institute of America)

Type	Waste Description	Principal Components and Sources	Approximate Composition (% by weight)	Moisture Content (%)	Incombustible Solids (%)	Heat Value Bt/lb Refuse as Fired	Auxiliary Fuel Btu/lb of Waste to Be Included in Combustion Calculations
0	Trash	Highly combustible waste: paper, wood, cardboard, cartons, including up to 10% treated paper, plastic, or rubber scraps—commercial and industrial sources.	Trash 100	10	5	8500	0
1	Rubbish	Combustible waste; paper cartons, rags, wood scraps, floorsweepings—domestic, commercial, and industrial sources.	Rubbish 100 (garbage up to 20)	25	10	6500	0
2	Refuse	Rubbish and garbage—residential sources.	Rubbish 50 Garbage 50	50	7	4300	0
3	Garbage	Animal and vegetable wastes—subsistence buildings, civilian cafeterias, markets, hospitals, prisons, clubs as sources.	Garbage 100 (rubbish up to 35)	70	5	2500	1500
4	Animal solids and organic wastes	Carcasses, organs, solid organic wastes—hospital, laboratory, abatoirs, animal pound, and similar sources.	Animal and human tissue 100	85	5	1000	3000
5	Gaseous liquid or semiliquid wastes	Industrial process wastes.	Variable	Dependent on predominent components	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey
6	Semisolid and solid wastes	Combustibles requiring hearth retort, or grate burning equipment.	Variable	Dependent on predominant components	Variable according to wastes survey	Variable according to wastes survey	Variable according to wastes survey

*From *Design Manual—Mechanical Engineering* (Naval Facilities Engineering Command, September 1974), p 3-2-3.

least five incinerators would be provided to process design quantities. Hardware requirement can be reduced by operating two shifts (17 hours burning time). If approximately 32.8 MBtu/hr (34.6 GJ/hr) of waste must be processed, a minimum of two incinerators will be required. Operating three shifts/day (23 hours burning time) reduces the processing requirement to 24.2 MBtu/hr (25.5 GJ/hr), which requires two incinerators. The solution to this problem might be to operate 24 hours/day, 5 days/week, and install four incinerators using units 1 and 2 for 24 hours, and units 3 and 4 for the next 24 hours. Units 3 and 4 could be started up during the final hour of operation of units 1 and 2 to increase effective burning time. The result is two incinerators operating at substantially less than nominal capacity (providing longer life and adequate flexibility to handle load variation), with a second pair immediately available for use when the first pair is down for maintenance. Peak waste loads can be processed either by increasing loads during normal operating hours or by operating during weekends.

Air Pollution Regulations

Stationary combustion source emission standards promulgated by the U.S. Environmental Protection Agency are minimum design requirements. Many states and local governments have adopted more stringent requirements with regard to flue gas, smoke density

and dust loading, and generation of smoke and fly ash during startup. Chapter 10 presents a reference on applicable air pollution control equipment.

Auxiliary Fuel

An auxiliary burner is usually provided in the primary combustion chamber for all but type 0 wastes,* and always in the secondary combustion chamber. Burners are sized so that proper combustion temperatures will be maintained when the lowest heat value wastes are burned. Selection of primary and backup fuel is based on availability, cost, and air pollution control requirements. Natural gas, manufactured gas, and No. 2, 4, 5, and 6 fuel oil can be used as auxiliary fuels. For project development, auxiliary fuel consumption requirements can be estimated as 16 percent fuel equivalent per MBtu/hr waste input; a package incinerator with with 19.5 MBtu/hr (20.6 GJ/hr) waste heat release rate requires 3.12 MBtu/hr (3.3 GJ/hr) auxiliary fuel, equivalent to 22.3 gal/hr (0.08 m^3) of No. 2 fuel oil. The fuel equivalent factor of 16 percent considers fuel required for startup and contingency.

Plant Location

Criteria provided in Chapter 3 are followed to determine plant location. The plant site is determined in project development to provide accurate cost estimates.

Plant Operation

Small-scale plants using package incinerators can have capacities of up to about 80 tons/day (72.6 t/day). For reliability, a plant usually has no fewer than two package incinerators. Maximum plant size is determined by the economic tradeoff between installing numerous predesigned package combustors or a lesser number of more reliable field-erected combustors. For estimating plant requirements, an annual load factor of 0.64 is used for each combustor. Because of slagging problems, 24 hours is generally the maximum continuous operation period of a package incinerator. Cooldown and manual slag removal require a minimum of 15 1/2 hours, usually necessitating backup units to handle continuously arriving waste loads. Batch-fed plants have less than rated capacity because of the cycle time required for charging, burning, burndown, and cleanout. If cooldown and cleanout requirements of package incinerators are known, maintenance duties can be effectively scheduled to avoid redundant outages.

Layout

An incinerator plant integrates several functional systems into a composite process.

Refuse-handling systems may include drives and off-street waiting area, scales, storage pit or tipping floor, cranes or front-end loaders, conveyors, hoppers, and rams.

Incinerators may include a drying chamber, grates, secondary combustion chamber, afterburner, and air-moving systems.

Air pollution control may be accomplished by gravity chambers, wet or dry baffles, cyclone separators, scrubbers with demisters, bag filters, electrostatic precipitators, and spark arrestors.

Residue handling may require hoppers, conveyors, rams, hauling equipment, and salvage facilities.

Furnace draft in the primary system requires fans and a stack. Plant auxiliary systems may require water supply, water reclamation and treatment, vacuum source, or compressed air. In addition, furnace operation requires controls and instruments.

A structure for housing all plant facilities accounts for up to 35 percent of a plant's capital cost General requirements of the plant include attractive appearance, durable construction, minimum maintenance, ease of housekeeping, adequate personnel facilities, and ease and safety in plant operation.

*IIA Classification, 8500 Btu/lb (19.8 J/kg). See Table 1.

3 SELECTION OF INCINERATOR PLANT SITE

General

Selecting a site for an incinerator plant is governed by haul distances, physical and load use factors, and projected installation development. Table 2 provides general site selection factors that are conventionally considered.

Haul Distances

Since collecting wastes and delivering them to the disposal site represents at least two-thirds of the cost of waste handling, siting the incinerator plant proximal to or centrally within areas generating most of the waste will generally be most economical. However, unavoidable nuisance factors (truck traffic, mechanical noise, visible steam plumes, high stacks) may require providing sufficient area and/or landscaping to isolate the plant. Time spent in moving waste from points of gen-

Table 2*
General Incinerator Site Selection Factors

Factor	Design Criteria	Comment
Accessibility	Incinerator should be near source of waste and near roads for trucks.	
Waste storage	–	Wind direction and distance to other buildings affect complaints about odors.
Steam plume from scrubbers	–	Locate away from areas which may be affected by fallout.
Soil conditions	–	Affect foundations and drainage.
Grades	Employ two levels where possible to facilitate charging and ash removal without hoisting and improve drainage of storm water and sewage.	–
Storage facilities	Required for waste and ash containers.	–
Electric wervice	Required for motors, lights, and controls.	–
Plumbing service	Hot water required for washing ash containers; storm and sanitary sewers required.	–
Climate	–	Affects type of enclosure.
Permanency	–	Consider possibility of moving incinerator for use at another installation.

*From *Design Manual–Mechanical Engineering* (Naval Facilities Engineering Command, September 1974), p. 3-2-6.

eration/collection to the incinerator plant and in returning to the collection route is generally more important than distance; therefore, proximity to points of waste generation is usually less important than siting near well-developed main roads with ready access to and from the incinerator plant. It is frequently economically favorable to locate an incinerator plant near garage and shop facilities for waste collection and residue disposal vehicles.

Installation Development

When siting an incinerator plant, consideration is given to direction of installation and development, installation redevelopment and consequent change in waste generation points, and future mission changes.

Physical Factors

Utilities

Utilities services factors governing selection of an incinerator plant site include requirements for two-way electrical feed to minimize plant outage, standby water supply, sewer service for sanitary and process water, gas pipelines, and telephone communication with management.

Access

It is most desirable to site an incinerator plant so that it is accessible over unrestricted two-way routes having on-off access in both directions. Turning across lanes of oncoming traffic is avoided. If possible, the site is conducive to separate routing for waste collec-

tion and residue-handling equipment. There is adequate vehicle waiting space ahead of the scale, and adequate space for employee and standby vehicle parking. Installation of traffic control lights may be required.

Topography

For both delivery and removal of residue, the natural flow of waste is by gravity; a sloping site will allow dumping of waste from collection vehicles at grade level on one side of the plant, and on-grade loading of residue-removal vehicles on the other side. A level site may require construction of ramps or depressed drives, excessive crane lifts, and added construction costs.

Meteorology

Consideration is given to meteorological factors and their relationships to air pollution potential. High stacks are used whenever possible. The site is selected so that prevailing winds can carry effluent gases over nonsensitive areas. However, favorable meteorological conditions do not usually eliminate the necessity of providing air pollution control apparatus.

Ash Removal

Only a small fraction of delivered waste is removed as ash and residue, so the location of a disposal site for ash and residue is generally not important in selecting an incinerator plant site.

Public Relations

Negative opinions about waste incinerator plants can be counteracted by emphasizing need for the facility; pointing out the careful consideration given to site selection; selecting a site harmonious with existing and projected land-use patterns; having a history of well-managed, nuisance-free waste disposal operations; and anticipating and thoroughly considering the value of possible negative opinions while the site is being selected.

4 RECEIVING, HANDLING, AND CHARGING OF WASTES

General Aspects of Handling

An incinerator plant includes an unloading area for waste delivered by collection vehicles. Delivered waste may either be discharged to a receiving pit and moved to the incinerator feed hopper by crane, or a tipping floor system may be used in which waste is moved to the incinerator feed hopper by a front-end loader. The unloading area may be opened or enclosed. Although open areas mean reduced construction costs, enclosed areas are favored for three reasons: (1) no exposure to adverse weather, (2) control of odors (air can be moved from the unloading area to the furnace and used in the combustion process), and (3) visual aesthetics. Provision may be made at the waste delivery point for either steam-cleaning or water-washing collection vehicles.

Floor Surfaces

Floor surfaces are usually made of impervious material cleanable by flushing. Adequate floor drains are provided at steam or water sources.

Pit Sizing

The length of the delivery pit is determined by the number of discharge spaces required to prevent truck tie-up during peak discharge hours. Total area includes a truck turning area. Separate entrances and exits are provided on opposite sides of the delivery area, and there are wheel curbs or tiedowns for trucks backing to the pit. Pit capacity can be determined from the storage requirement obtained from plant operating and waste delivery schedules. For typical military solid waste, a loose (uncompacted) bulk density of 100 lb/cu yd (59 kg/m^3) may be used to determine pit volume. Pit capacity does not normally exceed 200 percent of the daily waste generated, unless there are unusual waste storage requirements.

Backup

If all or a part of the plant breaks down, waste can be rerouted to an incinerator at another location or to a well-operated landfill, or it can be disposed of off-base by contract. If the waste delivery or storage area becomes overloaded, incinerator operating hours may be extended.

Ancillary Equipment

Water sprays can be provided around the pit for dust control, and fire equipment can be made available in the pit area. There are enough containers at the waste delivery points to separate and remove undesirable or unacceptable materials. Odors can be controlled by maintaining negative pressure in the pit area and using drawn air as combustion air. Sweepback ports are provided in the upper pit wall at operating floor level for disposal of floor sweepings and crane spillage. There is a regular schedule for cleaning the pit, and an adequate water supply and drain or sump system should be provided. The complete area is illuminated.

Overhead Crane

For military-scale incinerator plants using the pit/crane waste-handling system, an overhead, electrically driven, monorail crane hoisting a tined clamshell (grapple) is preferable to more costly bridge cranes. Crane size is a function of plant capacity (mass of waste stored, incinerator feed hopper capacity, incinerator feed rate, and weight and composition of waste); plant layout (location of pit and incinerator feed hoppers, clearances, expansion room); material flow (mixing of waste, distances, peak load hours); and crane duty cycle (required crane speed, charging, hopper feeding, waste rehandling and mixing, operator fatigue time).

Crane Structure

Crane structure is dictated by clearance requirements, alignment, ratio of dead weight to live load capacity, access for operations and maintenance, and proximity of anchorage, support, and end bumpers for rails.

Mechanical Crane

Mechanical cranes may have carbonized wearing parts, resistance to shock loading and reversal, centralized lubricating points, and clear access to routine maintenance areas.

Electrical Crane

Electrical cranes have unexposed contacts, full magnetic variable speed control, heat-tolerant motor, heavy-duty components, and a hookup separate from other plant components.

Operator

A small-scale operation would have remote crane control from an operating floor panel located to reduce operator fatigue and to maintain easy, safe access.

Spare Parts

Motor components, brake shoes and linings, cable, and other essential items are provided.

Clamshell

A grapple with tines spaced on 1 1/2-ft (0.46-m) centers with three-cable arrangement on a single hoist may be used. Bucket size depends on waste characteristics, incinerator feeder capacity, and charging cycle.

Front-End Loader

For small systems, the front-end loader is preferred over the pit and crane system, which is less reliable and requires longer time for repair or replacement. Front-end loaders are propane-fired and have filled tires to prevent blowout and vehicle outage. An enclosed, air-conditioned cab is often used to protect the operator from noise and odor.

Tipping Floor

A density of 150 lb/cu yd (89 kg/m^3), is used to size the tipping floor; the pile depth does not exceed 8 ft (2.44 m), and there is a 6-ft (1.83-m) skirt for pile relaxation. Sufficient area is provided for truck turning and for operation of the front-end loaders, and working walls are included to protect other plant elements from spillage. Water supply outlets and drains are sized to require only periodic manual cleaning. Plant design provides for gravity vents, exhaust fans, and fire protection and emergency exits over the tipping floor perimeter. A fire wall may be installed between the tipping floor and incinerator room to protect equipment and personnel.

General Aspects of Charging

Currently manufactured package incinerators include hardware to move waste into the furnace. Chapter 5 describes the type of charging equipment provided with each incinerator. Incinerator charging may be either continuous, semicontinous, or batch, and it may be manual, automatic, or a combination of the two. Incinerator feeding procedures may be either by ram charging or roof (drop) charging.

Ram Charging

Ram charging is a batch or semicontinuous incinerator feed procedure in which waste is dropped into a feed hopper and hydraulically pushed through a cooled guillotine door into the furnace. Air jets inhibit flashback when the ram withdraws. The feed hopper may be fed by hand, clamshell, front-end loader, or conveyor. Some designs use a feed hopper to direct the waste into the ram feeder, protect against spillage, and inhibit dust dispersion. The feed hopper height should not exceed 5 ft (1.52 m), because waste settling in the ram feeder may pile above the unit's mechanical height limit, requiring manual compaction from above. Some ram feeders may have a hydraulically driven vertical compaction device to reduce this problem.

Roof Charging

Roof or drop charging is most common in municipal-scale incinerator plants and has been used successfully in some small-scale systems. Waste is fed to a feed hopper and passes directly to the furnace from above. The hopper directs and controls the flow. Batch-fed units require hinged, sliding, or rolling gates to modulate charging and to close the opening at the top of the furnace. Continuous feeding requires that the hopper always be filled to maintain an air seal.

5 DESCRIPTION OF PACKAGE SOLID WASTE INCINERATORS

General

This chapter provides a general technical discussion of four currently available package solid waste incinerator systems. Because the systems share a similar process flow, the major thrust of the discussion is toward the uniqueness of the combustion equipment. It is emphasized that development of most package combustors has been relatively recent and that their applicability to installation use is not fully known. Information in this chapter was derived through field observation and contact with manufacturers and vendors. Some emphasis is placed on describing the general process flow of existing systems as they were observed in operation.

Process Flow

The process flow for all package systems is fundamentally the same. Mixed solid waste is collected and delivered to a facility where it is weighed and processed. The main processing operations are delivery, temporary storage, burning, ash removal, and air pollution control.

Solid waste deliveries are weighed at the facility's entrance by a standard platform scale. The weigh station may be manned or automatic. While requiring a somewhat higher capital outlay, an automatic system usually proves less costly than a manned one over the facility life. An automatic system may include either a standard automatic printing device or a remote-reading electronic system. In the latter, weights may be recorded in the operations office inside the facility. A signal at the weigh station indicates when the truck weight has been recorded.

There are various means of initially handling solid wastes delivered to the facility. For larger waste streams, a pit-and-crane operation may be desirable. Waste is dumped directly into the pit, which is usually designed to accommodate surge quantities. A ceiling-mounted crane moves material from the pit to further processing. Oversized bulky wastes are removed, and incombustible bulkies are separated for disposal or recycling. Combustible materials either too large or of too great a structural strength to be handled with mixed solid waste in subsequent processing stages may be diverted to an auxiliary heavy-duty shredder for breakdown. A system using a tipping floor and front-end loader is an alternative to the pit-and-crane operation. Delivered solid waste is dumped on the floor and moved by the loader either to a temporary storage area or directly to processing. Bulkies are handled as described above. Some municipal scale systems employ floor hoppers, in which delivered solid waste is dumped through the hopper grate and conveyed to further processing. Such systems have been moderately problematic from the standpoint of controlling oversized bulky materials.

Solid waste may be conveyed from the delivery point to temporary storage, to further processing, or directly to the incinerator. Although most currently marketed package incinerators are claimed to accommodate unprocessed solid waste, it is often preferable to shred the material. Shredding loosens and reduces the waste to a smaller and more easily handled particle size range, increases the surface/volume ratio and hence the material's combustibility, and, by mixing, makes the charge more homogeneous than unprocessed solid waste. Shredding increases the ease and efficiency of thermal processing and gives stability to total system performance. A wide variety of size reduction hardware is currently available, and selection of an appropriate unit depends heavily on the nature and quantity of the solid waste. In general, heavy-duty, vertical-feed, reversible-drive hammermills with replaceable hammer tips are adequate for the typical military base solid waste stream. Complete redundancy at this processing stage is desirable, since shredders are high-maintenance items, and continuous, reliable processing of solid waste is necessary.

It is generally preferable to keep solid waste moving through a system to avoid many difficult handling problems associated with storage of moist, putrescible materials. Often, however, temporary (up to 3 days) storage is necessary; this can be accomplished in the receiving pit. Shredded solid waste can also be stored in agitated bins, but this approach usually means higher capital investment and operating costs. If a tipping floor is used, it should be adequately sized to accommodate storage and surge requirements.

Shredded solid waste is fed into the package incinerator as required to operate the system at nominal capacity. Incinerator feeding is either continuous, semicontinuous, or batch, depending on the unit's design. Batch-fed incinerators are usually unfavorable, because they make it difficult to maintain continuity in steam production and solid waste disposal.

The final stage of the incineration process is usually afterburning. Afterburners should be temperature-activated and should limit the temperature range of com-

bustion products entering the secondary combustion chamber.

Most available package incinerators include at least semicontinous ash and residue removal. This phase is discussed separately in appropriate incinerator sections.

Since mixed solid waste can contain up to 25 percent ash, high mass emission rates may be expected. Wet or dry pollution abatement systems can be used; however, wet systems consume large amounts of power and cause a water treatment problem. Venturi scrubbers and high-draft water spray cyclones have successfully reduced emissions from solid waste incinerator systems, but their use could effect higher capital and annual costs from water treatment requirements. If a wet ash removal system is used, it is often convenient to use scrubber wastewater for quenching. Use of a scrubber usually requires a demister to inhibit mechanical deposition of droplets on the ID fan. Baghouses and electrostatic precipitators are the chief alternative dry collection systems. To reduce the possibility of filter fabric damage, a cyclone separator is used before the baghouse. High-temperature corrosion and abrasion-resistant media such as fluorocarbon are recommended. Utility operating costs of baghouses and electrostatic precipitators are generally comparable. A baghouse normally has a large ID fan horsepower requirement, since pressure drops across the unit can be great. Precipitators are large electricity consumers. A precipitator-based design places a low-efficiency cyclone ahead of the ash storage bin to remove any hot cinders which may cause an explosion. Material collected in the cyclone for both the fabric filter and electrostatic precipitator systems should be quenched before admission to the ash bin. A precipitator system may require preconditioning of the flue gas with sulfur trioxide. Since solid waste contains very little sulfur, the particulate material's sensitivity at the collection electrode may adversely affect the unit's collection efficiency.

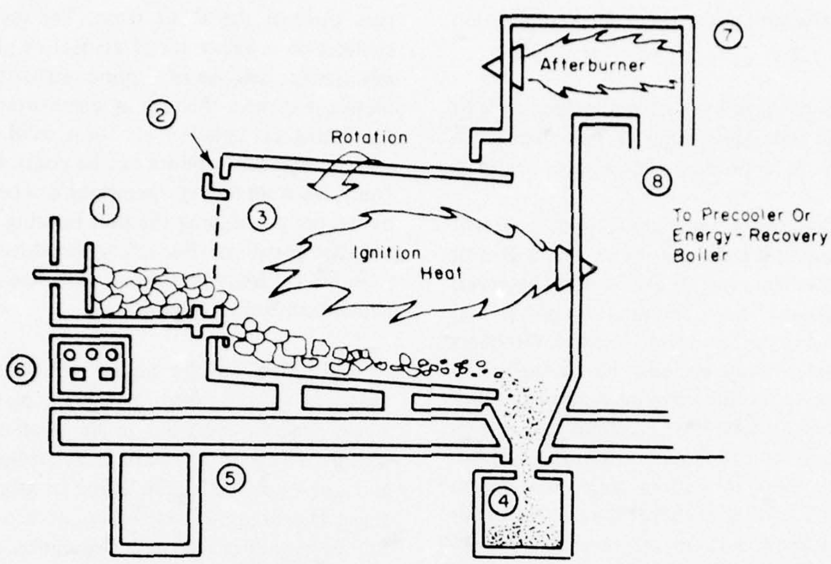
Preparing and using solid waste as a fuel can create numerous environmental hazards. Air hoods are required for shredders whose off-gases contain up to 0.05 percent of the feed as entrained dust. High chloride emissions from the combustion process are possible, because the heavier fractions of solid waste may contain substantial quantities of polyvinyl chlorides. If large quantities of plated metals are present, high concentrations of zinc, tin, cadmium, lead, and antimony will be emitted as a submicron heavy aerosol; the aerosol is formed when these metals are reduced and evaporated in the fuel bed and these vapors oxidized as they pass through the flame front. The metals will either coalesce as a heavy metal aerosol or plate out on the ash matrix. Because of varying resistivities, some trace metals may pass through an electrostatic precipitator. By taking combustion air from solid waste delivery and storage areas, odors can be controlled effectively. Noise from shredding operations can be reduced either by properly designing the unit housing or by installing acoustic partitions. For safety, shredders should be surrounded by blast partitions, with low-resistance blast panels installed on the ceiling.

Depending on the nature and quantity of solid waste being processed, profitable materials recovery stages may be included in the system. A variety of proven hardware is available for magnetics recovery, and can be placed either before or after the shredding stage. If economical, an aluminum recovery system can follow magnetics recovery. Separation of glass and cullet is more difficult, usually requiring additional shredding and agitated screening and wet recovery stages such as flotation. Such recovery systems require high investment and operating costs. It has been demonstrated frequently that the most economical way to isolate salvageable materials from other wastes is to conscientiously practice source segregation.

Rotary-Kiln Incinerator

The primary combustion chamber of a rotary-kiln incinerator is a slightly inclined, refractory-lined cylinder (Figures 2 and 3). In most commercially available units, the shell is prefabricated, so that the kiln may be shipped as a unit. Refractory materials are customarily made to specifications given in terms of thermal tolerance and resistance to abrasion and corrosion.

During combustion, the kiln rotates around its longitudinal axis of symmetry, continually mixing the charge mechanically as it is being conveyed to the discharge end. The constant motion effectively breaks up caked layers on the charge's surface, continually exposing fresh surfaces and increasing combustion efficiency. In a well-operated unit, there is approximately 92 percent combustion. The combustible material dries quickly, ignites, and burns thoroughly. Combustion air is preheated by reflected heat from within the kiln. The ignition burner is located at the discharge end of the kiln and may be fueled with light or heavy oil, gas, or flammable liquid waste material. Temperatures sufficient to sustain ignition are normally maintained by the burning charge after startup. Additional fuel can be supplied to the kiln when wastes having a heating value too low to support self-combustion are being burned.



1 Coarse RDF Auto-Feed (Hopper, Pneumatic Feed, Slide Gates)
2 Forced Air
3 Refractory-Lined Rotating Cylinder (Primary Chamber)
4 Ash Hopper (Incombustibles)
5 Support Frame And Piers
6 Control
7 Secondary Chamber
8 To Appurtenances

Figure 2. Rotary-kiln incinerator.

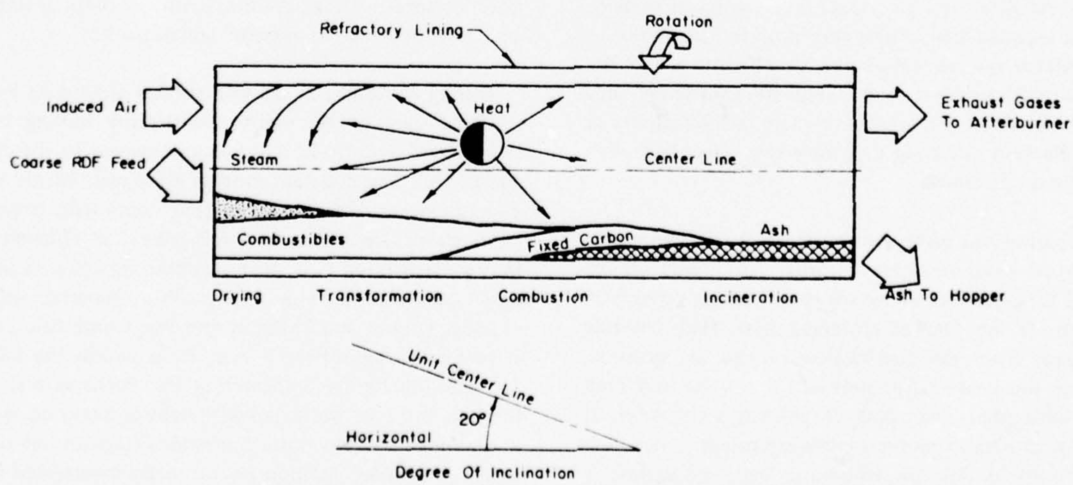


Figure 3. Operation of rotary-kiln incinerator.

This auxiliary fuel may be mixed with the charge or burned in either an auxiliary burner or the ignition burner.

The rotary kiln can burn mixed solid waste as received. Oversized bulky wastes are usually shredded to insure complete combustion within reasonable detention times. Feeders on commercially available units are designed to accommodate feed variability. Sludges and similar wastes are usually mixed with a variable supply of solid waste before charging.

A ram feeder can be used to charge the primary chamber. Ash is continuously discharged through a port in the bottom of the refractory-lined firing hood at the end of the unit. The discharge end firing hood is equipped with labyrinth seals and heat-resistant gaskets to inhibit air leakage.

The detention time of solid material passing through the kiln is controlled by the cylinder's slope (usually 20°) and its rotational speed. The velocity of gases passing through the cylinder is determined largely by combustion air requirements. Gas velocity is partially controlled by modulating the induced draft fan and damper, located after the pollution control equipment. Gases from the primary chamber pass into the afterburner's section, where residual volatiles are combusted in an oxygen-rich atmosphere.

Automatic temperature controls are used. A primary pyrometer monitors the temperature of the gases leaving the kiln. When the exit gas temperature falls below a predetermined set point, gas flow to the burners increases. A second control monitors gas temperatures in the afterburner. When the afterburner temperature falls below the set point, the burner heat release increases. When the temperature exceeds the upper set point, the burner automatically modulates downward. An additional optional temperature control apparatus from a gas precooler shuts down the burners, fan, and feeder when gas temperatures exceed a safe upper limit. An alarm in the control module activates after safety shutdown.

Rotary-kiln incinerators normally operate with 140 percent theoretical air in the primary chamber. Operating temperatures in the kiln are usually between 1400°F (760°C) and 2300°F (1260°C, with a recommended operating range between 1200°F (649°C) and 1800°F (982°C).

Due to thermal losses and the addition to excess air, gases leaving the afterburner section normally range between 1500°F (816°C) and 1800°F (982°C). If these gases must pass directly to the air pollution control equipment, they must be precooled by either a water spray, addition of tempering air, or a heat exchanger. In the latter case, recovered heat may be used to heat combustion air or used elsewhere in the processing plant.

Bottom ash and residue drop into a water-sealed ash-handling unit below the kiln. A grate is sometimes placed in front of the bottom ash-handling hardware to trap oversized combustibles such as cans and pipes, but this can cause exit blockage and ash backup. If the bottom ash is sufficiently fine, water-cooled screw augers can be used for ash removal.

Some available rotary-kiln incinerators are equipped for either countercurrent or concurrent gas/charge flow (Figure 4). Concurrent flow is used for drier, more heterogeneous wastes. During carbonization of solid fuels, flue gases are completely burned in the afterburner, permitting higher thermal loading in the combustion zone. Countercurrent operation is suitable for incinerating sludges. Combustion products are used to dry the incoming charge, permitting higher combustion efficiency.

Field erected rotary kiln incinerators have little long term operating history. Notable installations are the Chicago Southwest incinerator and the Dow Chemical Plant in Midland, MI. Small rotary kilns are employed to process specialized waste in certain demilitarization operations.

Controlled-Air Incinerator

Controlled-air incinerators have recently gained popularity in solid waste incineration, principally because inexpensive, small-capacity units are being manufactured. Larger package units (1.25 ton/hr capacity range) are available in two major configurations (Figures 5, 6, and 7). Both of these units operate on the same principle: the charge is fed into a primary chamber, ignited, and then burned in a secondary chamber in which excess air and additional heat are supplied. A well-operated controlled-air incinerator will achieve between 80 and 93 percent combustion.

A drawback to the controlled-air system is the lack of charge mixing. This deficiency prevents the material

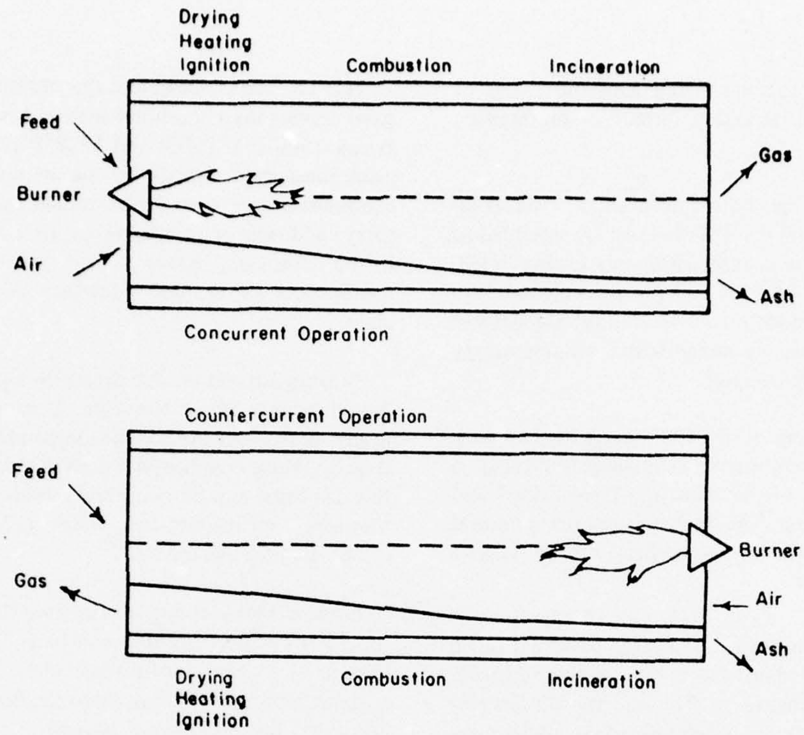


Figure 4. Concurrent and countercurrent operation of rotary-kiln incinerator.

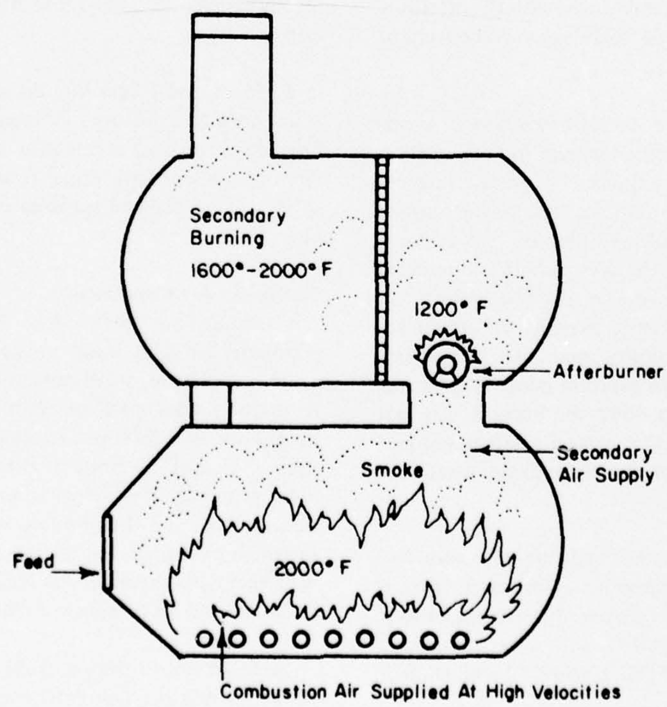


Figure 5. Controlled-air incinerator (first major configuration).

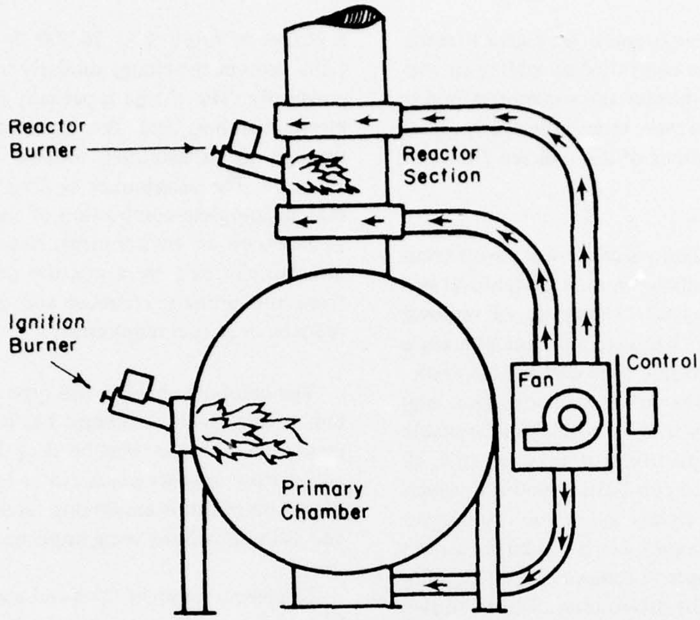


Figure 6. Controlled-air incinerator (second major configuration).

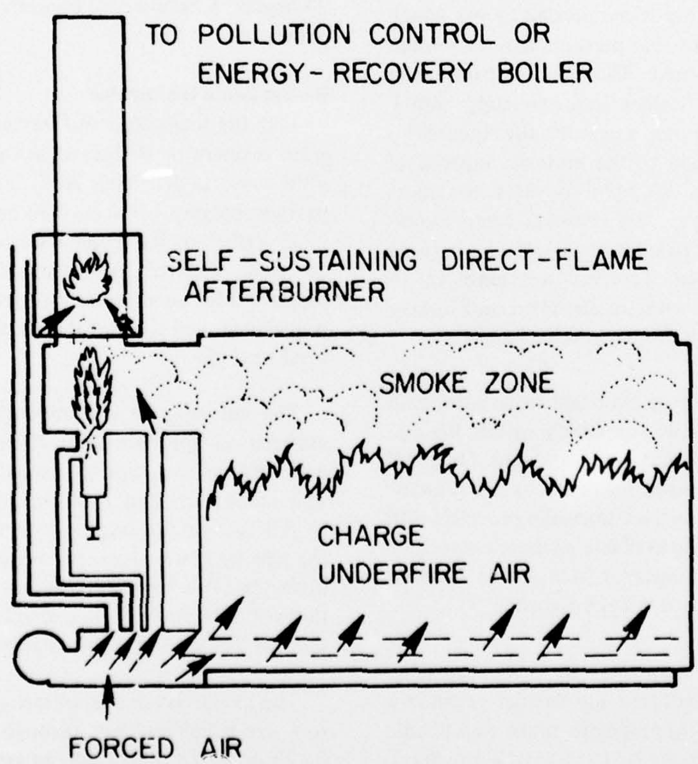


Figure 7. Controlled-air incinerator (second major configuration).

from being burned completely and often causes furnace pulsations. Temperature is controlled by adding air and auxiliary fuel to the afterburner and sometimes modulating the air supply. However, in an improperly operated unit, the carbon content of ash emitted from the furnace is often high.

Several vendors offer controlled-air units with semiautomatic feeders and semicontinuous ash-removal systems. Currently, however, fully automatic ash removal is not proven technology. Because of high-temperature slagging in the primary chamber, the unit has a comparatively large fraction of downtime, with correspondingly high operating and maintenance costs. Most available units require moderate quantities of auxiliary fuel, although recently developed combustion controls which automatically modulate excess air in the afterburner have reduced clean fuel requirements. Underfire air has been modulated in attempts to achieve constant quality of off-gases passing to the afterburner. There are two basic controlled-air incinerator configurations. The first is comprised of two "piggy-back" combustion chambers, in which refuse is charged to the primary (lower) chamber through an *air curtain. The entryway* is surrounded by an annular ring of compressed air jets, which provide a conical air blast that prevents flareback when the charging door is opened. When the temperature in the primary chamber reaches approximately 600°F (316°C), a stream of air passes over the fire. Incombustible materials precipitate to the grateless bottom of the chamber, and the remaining solids, gases, and odors rise to the upper or secondary chamber where excess air is added. Thorough mixing is maintained by baffling excess air as it is added. Temperatures range up to 1500°F (816°C) in the primary chamber, and usually up to 1200°F (649°C) in the secondary chamber.

Most units of this configuration feature an automatic temperature-activated indicator which signals the operator when charging should begin and end. On small units, the charge is delivered manually to the primary chamber. Batch ram loaders are normally provided with larger units. Commercially available package controlled-air incinerators range in capacity from 200 to 2400 lb/hr (91 to 1089 kg/hr) for IIA Type 1 waste.

The second type of controlled-air incinerator (Figures 6 and 7) uses a substantially smaller secondary combustion chamber. Intermediate units can handle from 1350 to 8100 lb/loading (612 to 2674 kg/loading), and larger units can be built to specification. The largest proven incinerator of this configuration can accept a charge of more than 36,000 lb (16 330 kg). These units process the charge similarly to the units discussed previously. The charge is partially pyrolyzed in the primary chamber, and the products are then passed through an afterburner located above the primary chamber. The afterburner is fired with clean fuel and effects complete combustion of the pyrolysis products in an excess air environment. Newer models feature an afterburner fired by a mixture of pyrolysis products from the primary chamber and preheated air, which reduces clean fuel requirements.

The chief drawback to this type of controlled-air system is that when the charge has been completely processed, the furnace must be shut down and allowed to cool before another batch can be loaded safely. Recent design innovations employing semicontinuous charging and ash removal are being implemented.

Numerous municipalities and some installations now have this type of incinerator in operation. Of all package incinerators received, the starved air has the longest operating history, about 10 years; however, it has yet to be demonstrated that this type of unit can operate 24 hr/day, 5 days/wk on *as-received military* or municipal waste.

Basket-Grate Incinerator

Like the rotary-kiln and starved-air units, the basket-grate incinerator (Figure 8) is capable of firing mixed solid waste as delivered. Available units have input capacities ranging between 160 and 6000 lb/hr (73 to 2722 kg/hr) of IIA Type 1 waste. The primary chamber is an inclined (30°) truncated cone-shaped grate supported by an externally driven frame. The chamber is insulated, and the shell is normally fabricated of structural steel plate.

The basket grate is semicontinuously charged with material on approximately 20 percent of its total volume and rotated slowly around the cone centerline. The inclination and rotation cause heavier materials to fall toward the larger (outer) basket diameter and the smaller materials to fall toward the smaller (inner) diameter. The three-dimensional self-raking effect of the virtually endless grate maximizes mechanical and thermal destruction of the charge.

The charge is retained on the grate until it is reduced to a size which can pass through the grate slots (about 0.125 in. [3.18 mm]) into an ash hopper or secondary incineration chamber. Large combustibles can be removed periodically from the grate by means of a grated

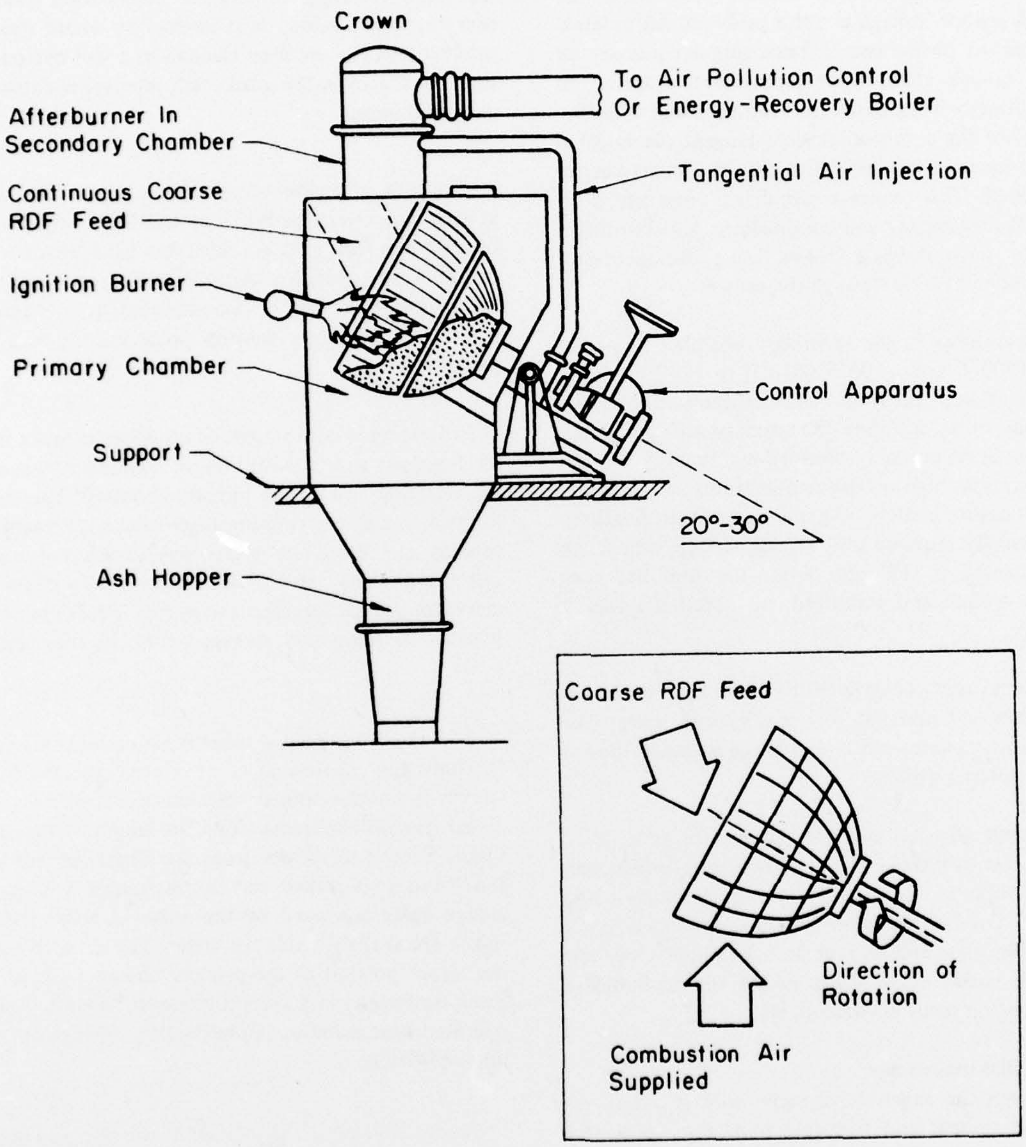


Figure 8. Basket-grate incinerator.

plate which can be lowered from the basket bottom. Some problems have been experienced with bulky incombustibles accumulating in the cone which reduce available combustion volume, and with fine combustibles sifting through the grate and burning in the ash hopper. Negative relative pressure within the primary chamber induces air through the ash collector, so that ash and residue leakage is not a problem. An external fan mounted on the swivel frame supplies primary air to the furnace. Distribution pipes divert a portion of the air directly beneath the firebed to provide underfire air. Part of the combustion air is tangentially injected into the secondary combustion chamber located above the firebed. This causes a turbulence zone which effects efficient mixing and combustion. Afterburning is normally self-sustaining. Gases leave the secondary combustion chamber through the crown.

Temperatures in the secondary chamber range between 1500°F and 2100°F (816°C to 1149°C). Temperature is controlled by automatically varying the quantities of air entering the primary and secondary chambers in an inversely proportional manner. In normal operation, high off-gas temperatures can be maintained at approximately 70 percent excess air. Auxiliary fuel is usually required only during startup, which can be completed in 15 min. After the unit has been brought on-line and stabilized, no additional fuel is necessary.

Available units achieve 90 to 96 percent reduction of combustible materials for IIA Type 1 waste. The quantity of incombustible residue remaining in the ash rarely exceeds 5 percent.

The basic flaw of the basket grate is the grate itself. Bulky incombustibles collect and reduce effective combustion volume, ultimately requiring cooldown and cleanout. Combustible fines have been observed to sift through the grate and burn in the ash hopper. Only one operating basket grate exists in the United States—a demonstration plant in Grafton, WI.

Augered-Bed Incinerator

Although the augered-bed incinerator is a very recent development and therefore unproven, successful demonstrations indicate that engineering problems are relatively minor. Units are expected to go on-line within 1 year, and experience soon thereafter will provide the operating data necessary for improved design. Currently manufactured package units have capacities of 1 and 5 tons/hr (.9 and 4.5 t/hr).

The augered-bed incinerator is comprised of a refractory-lined cylindrical primary combustion chamber that contains a rotatable auger (Figure 9). The chamber is fed continuously by a live-bottom feed conveyor. Combustion takes place in an excess air environment as the auger conveys the charge throughout the length of the chamber. High-temperature combustion products pass through a coiled heat exchanger where steam is produced. Gases are then cleaned in a wet cyclone before passing from the stack. Ash removal is automatic and continuous.

The unit is capable of processing mixed solid waste as delivered. Oversized bulky materials too large to pass through the feed port are separated from the delivered waste. Waste streams containing a high percentage of bulky materials can be accommodated by adding a shredder between the delivery point and the feed hopper.

Processing is continuous. Solid waste enters a floor-level hopper and is moved on an inclined conveyor to the charging end of the primary chamber. The charge burns as the slowly rotating auger moves it through the primary chamber. The auger conveys ash and residue out the discharge end of the chamber to a chain belt conveyor, which transfers the mostly sterile, inert end product to temporary storage before its ultimate disposal.

The auger is a hollow spiral flight carried by a tubular shaft. Combustion air is introduced into the downstream end of the primary chamber and forced through an air passage extending along the length of the spiral flight. Forced air passes from the flight interior into the primary chamber and is discharged within the charge being conveyed by the auger. A water passage in the spiral flight cools the auger. The air then enters the upper portion of the primary chamber where off-gases are burned in a second combustion zone. A well-operated unit achieves approximately 95 percent volume reduction.

An ignition burner is located at the charging end of the primary chamber. Gas or fuel is normally used, but flammable liquid wastes can also be fired. In normal operation, the ignition burner operates only during startup, which requires about 15 min. When combustion becomes self-sustained, no auxiliary fuel is required. The unit can be shut down in 20 min.

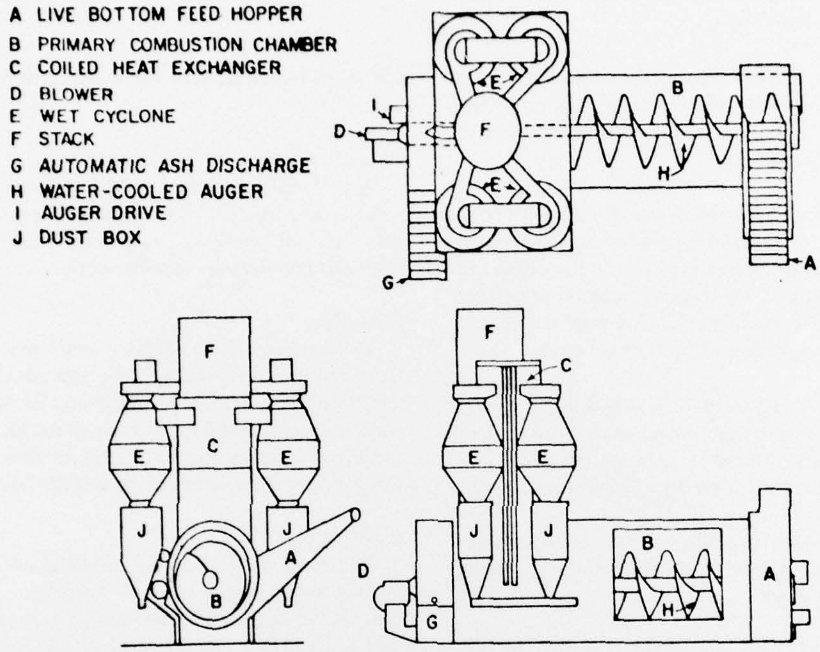


Figure 9. Augered-bed incinerator.

Available units include induced air, counterflow wet cyclones for air pollution control as part of the package system.

Variable drive controls are provided on all functions to adapt to fluctuations in the type and quantity of solid waste being processed. Hydraulic drive systems are provided for the auger, feeder, and ash removal apparatus, and standard belt drives are provided for blowers.

Only one augered-bed incinerator exists in the United States (Jacksonville, FL), and it is an operating prototype. No operational data have been published to permit performance assessment.

Comparative Ratings of Package Incinerators

General

The comparative rating system applied in this investigation was adapted from one established to evaluate waste incineration/reduction options at a particular site.[3] In adapting the system to meet the general requirements of this investigation, numerous assumptions were made regarding waste generation rate and characteristics and plant capacity. The comparisons are presented as a general indication of the current technical status of package incinerator technologies. The feasibility of applying a particular technology at a given location can be determined only through a detailed and comprehensive study in which site-specific characteristics and requirements are carefully considered. Each criterion in this evaluation is briefly defined below.

Comparative Rating Criteria

Like other acceptable technologies, an installation waste incineration system must be reliable, practicable

[3] *Refuse Incinerator/Heat Reclamation Boiler Facility, Naval Station Mayport, FL* (Greenleaf/Telesca, Planners, Engineers, Architects, Inc., 1975).

on the operational level, conservative, environmentally compatible, reasonably economic, and must have an adequate operational history by which to predict and guarantee its performance.

Reliability is strongly tied to dependability. It is a measure of the degree to which a design follows a proven art and the potential of the designed system to withstand predictable wear.

Practicability refers to the degree of a system's complexity which could make its proper performance contingent upon highly skilled personnel. It is related to ease and intensity of day-to-day operation, preventive routine and cyclic maintenance requirements, and procurement and installation of replacement parts.

Conservation refers to the degree to which a system reuses or recaptures energy and materials, or the extent to which a system consumes those resources supplied by external sources. It is a measure of system efficiency.

Environmental compatibility is measured by the impact of system operation on the immediate air, water, and land environments.

Operational history is the length of experience with similar equipment for processing waste. Operational history forms the critical basis for predicting and guaranteeing the life cycle performance of a system within a reasonable boundary of accuracy.

Economy is directly measurable in terms of first cost (including capital investment and first-year expenses such as startup) and recurring costs (annual and cyclic operation costs).

Ratings of Package Incinerators

Table 3 summarizes comparative ratings for package waste-to-energy systems. The ratings generally apply both to package systems firing as-received waste and those firing once shredded solid waste, although minor differences in the ratings are revealed if each is considered separately. In the rating system in Table 3, each system was given a score in each category ranging between 1 and 4, from best to poorest, so that each row item totals 10 points. The best possible total score is 15, and the worst is 60. A "satisfactory" score is considered to range between 22.50 (averaging 1.5 on each item) and 30 (averaging 2.0 on each item). Based on this criterion, no current package incinerator technology is considered to be "satisfactory." The controlled-air system is the relative best, with an average item rating of 2.33 and a total score of 35 (16.7 percent poorer than marginally satisfactory).

6 ASH HANDLING AND DISPOSAL

General

Ash discharged from the furnace is usually quenched before being transported to disposal. Quenched ash normally can be landfilled and is subject to the same restrictions as conventional solid wastes.

Quenching

Most package incinerators provide ash quenching. Batch-fed furnaces usually have receiving hoppers in which ash is quenched by spraying. Some batch-fed and most continuously fed furnaces discharge ash to a water bath, which uses circulated scrubber water if a wet scrubber is provided for the air pollution apparatus.

Handling in Plant

Batch-quench systems are normally overhead, with ashes dumped into a truck or container; continuous-quench systems remove quenched ash from the water bath to a truck or container by inclined conveyor.

Hauling

Either closed containers or open-body vehicles are adequate for hauling quenched ash from the plant to the disposal site if trucks are used. Closed containers may be used if a rail spur is available. Choice of hauling method should be based on the distance between the incinerator and the disposal site.

7 INSTRUMENTATION AND CONTROLS

General

Instrumentation refers to equipment used to indicate and/or record physical conditions which are relayed to operating personnel as signals. Controls refer to devices which can change physical/chemical conditions. Through intelligent application of instruments, process conditions are measured in a manner which will effectively aid in controlling the incineration process (modulation of combustion air, charging rate, auxiliary fuel, grate speed, etc.). Instruments and controls interact to (1) protect equipment and operating personnel (e.g., safety alarms to warn against overheating of fur-

Table 3
Comparative Ratings of Package Solid Waste Incinerators

	Controlled Air	Rotary Kiln	Augered Bed	Basket Grate
Reliability				
Prior art	1.5	2	3.5	3
Predictable wear	1.5	2	4	2.5
Total	3	4	7.5	5.5
Practicability				
Complexity	3	3	2	2
Ease of maintenance	2	2	3	3
Ease of operation	2.5	2.5	1.5	3.5
Total	7.5	7.5	6.5	8.5
Conservation				
Material recovery	2.5	2.5	2.5	2.5
Power consumption	2.5	3.5	2	2
Fuel consumption	4	2.5	1.5	2
Total	9	8.5	6	6.5
Environment				
Air	1.5	2	3.5	3
Water	2.5	2.5	2.5	2.5
Land	3	2	3	2
Total	7	6.5	9	7.5
Experience				
Number of installations	1.5	2.5	3	3
Operational history	1.5	2.5	3	3
Total	3	5	6	6
Economy				
First cost	2.5	3	2	2.5
Recurring costs	3	2	2	3
Total	5.5	5	4	5.5
Grand Total System Rating	35	36.5	39	39.5
Mean (Standard Deviation)	2.33 (0.75)	2.43 (0.46)	2.60 (0.76)	2.63 (0.48)

Possible Best: 15 Total

Possible Worst: 60 Total

naces and ducting, failure of quench water, electrical power failure); (2) to protect the environment (sensors for air and water pollutants); (3) to provide monitoring and background information on plant performance; and (4) to optimize operations and economic effectiveness (reduce labor and human error through automation). The degree and sophistication of an integrated instrument-control system depends on plant size and economics.

Centralization

A fully instrumented control room or, at minimum, a central instrument panel, is provided so plant performance can be seen at a glance. The room or panel has an unobstructed view of all major unit operations in the plant.

Temperature Instruments

Optical pyrometers for flame and wall temperatures ranging from 2200°F to 2500°F (1204°C to 1371°C) are provided. In addition, there are shielded chrome-alumel thermocouples for furnace temperatures ranging from 1400°F to 1800°F (760°C to 982°C) and iron-constantan thermocouples for duct temperatures down to 100°F (38°C). Gas- or liquid-filled bulb thermometers for duct temperatures below 1000°F (538°C) and for ambient temperatures and water temperatures should be supplied.

Draft Pressure Instruments

For readout near the point of measurement, manometers with inclined water gauges are provided; for remote readout, diaphragm-actuated sensors are furnished.

Gas/Liquid Pressure (1 to 100 psi) Instruments

Bourdon-type pressure gauges are used for direct readout. For remote readout, diaphragm-actuated sensors are used.

Gas Flow Instruments

Pitot tubes and orifice or venturi meters with differential pressures measured by draft gauges are used.

Liquid Flow Instruments

Orifices with differential pressure measurement, propeller-type dynamic flowmeters, and weirs are provided.

Smoke Density Instruments

An opacometer in the stack for photoelectric pickup of a transversing light beam is normally used.

Motion Instruments

Stoker and conveyor drives and tachometers for fan speed are provided.

Visual Observation

Shielded observation ports to the furnace are installed. When appropriate for safety reasons, mirror systems are used for indirect observation of critical unit operations and/or processes.

Weighing Instruments

A truck platform scale for weighing waste deliveries and outgoing ash and residue is installed.

General Electrical Instruments

Voltmeters, ammeters, and wattmeters are furnished, as appropriate.

General Measurements

An incinerator plant includes all instrumentation required to determine (1) weight of incoming and outgoing material; (2) overfire and underfire air flow rates; (3) temperatures and pressures in the furnace, along gas passages, in dust collectors, and in the stack; (4) grate speed; and (5) electrical power, fuel, and water consumption.

Temperature Measurements

At a minimum, equipment is installed to measure temperatures of incoming air (ambient) and of gases leaving the combustion chamber, temperatures at the settling chamber outlet and at the cooling chamber outlet, and temperatures of the dust collector inlet and outlet, stack furnace, and induced draft fan inlet.

Gas Flow Measurements

Equipment is provided to measure total underfire and overfire air flow and the percentage of each to the total flow, and gas flow through the dust collector and stack.

Draft Measurements

Draft pressures are measured at the underfire and overfire air ducts, stoker compartments, sidewall air duct, sidewall low furnace outlet, dust collector inlet and outlet, and induced draft fan inlet.

General Control System

The manufacturer or vendor of a package incinerator generally provides an adequate control system. The basic elements of a control system are performance standard, instruments to sense actual performance, ca-

pability to compare actual and standard performance, and a device to effect a corrective change. Automatic control systems are preferable to manual systems.

Air Controls

Controls for modulating underfire and overfire air are installed.

Draft Controls

Controls to modulate furnace draft (manually or automatically adjust ID fan draft and stack draft) are furnished.

Gas Controls

A temperature-activated system to modulate the quantity of tempering air to off gases from the furnace is furnished. A control (with alarm) that will open an emergency bypass if excess gas temperature exceeds a safe, preset limit is installed.

Feed Controls

Controls to modulate feed to the incinerator are provided.

Fuel Controls

Controls to modulate primary and auxiliary fuels required to maintain desire furnace temperatures are provided.

8 OPERATION AND MAINTENANCE

General

Effective operation and maintenance of an incinerator plant is essential in waste management and can be achieved by integrating management and personnel, operation guides, performance records, performance data analysis, and routine maintenance and repairs. The following sections point out some aspects of operation and maintenance of incinerator plants which have been successful in numerous locations.

Management and Personnel

The plant supervisor is normally present at major work inspections and consultations during construction so that he/she can become familiar with each component of the new plant. Training of operating personnel begins when the plant is in the latter stages of construction, so that they can work closely with representatives of manufacturers and contractors. An organizational chart showing number of shifts, number and types of operating personnel, and standby and maintenance manpower is developed.

Operational Guides

A scaled engineering or pictorial drawing of the plant showing all its major components is posted, and at least one set of formal engineering drawings, equipment manuals, catalogs, and spare parts lists is maintained at the plant. A manual describing the tasks that must be performed during a typical shift, safety precautions, and procedures for working in different plant areas is also maintained.

Performance Records

Frequent review of performance records can economize plant operations. Performance evaluation is based on routinely recorded or computed data, including residue characteristics, volume and weight reduction of waste, quantity of pollutants released to the atmosphere, operating costs per ton of waste processed, personnel records, and consumption of supplies, materials, and utilities.

General Aspects of Recordkeeping

Maintaining accurate records of incinerator plant operation is essential for performance measurement and cost accounting. Recordkeeping categories are waste quantity and composition, waste handling, furnace, utilities, and maintenance.

Waste Quantity and Composition

Data are maintained on the quantity of waste in the pit or on the tipping floor at the beginning and end of a shift or day; number of trucks delivering waste; number of tons recieved; average truck load; and quantity of waste processed. Waste is periodically analyzed in the laboratory, and data on the heating value, moisture content, and percentage of combustibles are maintained. For ash and residue, records reflect the weight and volume of the material removed. Ash and residue are analyzed periodically to determine the percentage of unburned combustibles and thus the furnace's efficiency. Data on the cost of residue and ash disposal and periodic disposal of solid waste are maintained.

Waste Handling

Data are recorded on the number of trips of each crane per shift or per day, and on the amount of fuel required for front-end loader operation.

Furnace

Continuous periodic furnace temperature data are maintained, and the range and average calculated on a

daily basis. Records are kept for waste burning time and for hours of incinerator operation. Stack emission records are kept separately, and include draft recordings, total and excess air used for combustion, temperature of off-gases, and quality and quantity of gaseous and particulate emissions.

Utilities

The cost and consumption of water, electricity, fuel oil, gas, and communications are recorded by use categories.

9 PERSONNEL FACILITIES AND SAFETY

General

The design and operation of an incinerator plant provides certain minimal facilities for the comfort, protection, and safety of operating personnel. The size and operating schedule of the incinerator plant determines the extent to which personnel facilities are required.

Hygienic Considerations

Potential health problems associated with incinerator operation include excessive noise, ingestion or disease-producing organisms, ingestion of chemical toxins, contamination of skin with infectious or poisonous substances, and irritation from dust and heat. Control of rodents/pests is a significant part of a plant maintenance program.

Hazards

The nature of waste and the equipment used to handle it can present such hazards as injuries, fires, and explosions. If a shredder is used, it is surrounded by acoustic/blast partitions with breakaway sections in the plant roof directly above it.

Employee Facilities

Adequate sanitary facilities at an incinerator plant minimize health hazards and contribute to employee morale and labor productivity by contributing to favorable working conditions. Minimum employee facilities include sanitary toilets, a readily accessible supply of potable water, and separate lunch and locker rooms. The extent to which employee facilities are provided depends on plant size and operating schedule, local building codes, minimum sanitation requirements, and economics.

Sanitary Toilets

Wastes from sanitary toilets are disposed of either by discharging to a sanitary sewer or in a manner complying with prevailing laws.

Water Supply

Potable water is provided from the installation system. Potable water is required for hand washing, showers, drinking water, toilets, and lunch room facilities, and may also be used for cooling water, floor washing, dust control, fire fighting, and washing collection vehicles and waste containers.

Lunch Room

A separate lunch room is provided away from the waste delivery area. The lunch room is ventilated independently of the rest of the building. In large plants, a refrigerator, sink, table, chairs, and cooking facilities should also be provided.

Locker Room

A separate locker room large enough for at least two metal lockers per employee is furnished. Handwashing and shower facilities are provided within the locker room, with sanitary toilet facilities located adjacent to it.

Ventilation

Adequate ventilation for heat and dust is provided.

Illumination

To promote efficiency and safety, excellent lighting is provided near the delivery pit, moving machinery, stairways, ladders, dumping area, charging and stoking area, machinery maintenance area, blowers, and other potentially hazardous locations.

General Safety Equipment

First-aid kits, fire extinguishers, fire hose (wall nipples and hydrants), intercom, handlights and safety lights, and equipment safety devices are furnished.

Employee Safety Equipment

Hard hats, masks, goggles, protective clothing, safety shoes, fire blankets, a cot, and stretchers are provided.

Employee Safety Training

Safety training for operating personnel can be administered through on-the-job programs, the area fire marshall, and through agencies such as the American Red Cross and American Public Works Association. Employee safety training should include periodic refresher courses.

10 POLLUTION ABATEMENT

Air pollution emissions from incinerators are fly ash, hydrocarbons, sulfur oxides, nitrogen oxides, chlorides, carbon monoxide, and heavy metals. Steam vapor is a potential visibility and road icing hazard. The forthcoming *Air Pollution Control Design Manual** was written to facilitate identification of air pollution emission rates and to help select control equipment required to meet state and Federal air pollution compliance levels for incinerators and boilers.

The level of uncontrolled incinerator emissions depends on the nature of the refuse being fired, the feed rate, and the incinerator design. Section 2 of the draft *Air Pollution Control Design Manual* presents waste classifications, incinerator types, emission factors, and emission measuring techniques.

Each basic control equipment type, including cyclones, scrubbers, electrostatic precipitators, and fabric filters, is discussed individually. Included is a discussion of the appropriate basic control theory, various equipment types, collection efficiency, pressure drop, operating requirements and limitations, application, construction of materials, and advantages and disadvantages relative to other control types.

For project development and the preparation of environmental impact assessments, it may be necessary to ascertain the effect of emission rates on air quality. One section of the manual discusses stack emission dispersion production techniques.

The manual also deals with techniques of handling wastewater from the incinerator quench systems and air pollution control apparatus.

11 CONCLUSIONS

Existing Army technical manuals providing instructions and information for the design of installation-scale incinerators do not reflect the accelerating technological changes that have taken place during the past few years. Such changes have affected all unit operations normally associated with the incineration of solid waste.

The potential applicability of the starved-air, rotary-kiln, basket-grate, and augered-bed combustors cannot be fully assessed through literature review and the claims of manufacturers and vendors. There is a comprehensive lack of details on maintenance and operation requirements for the incinerators and auxiliary equipment discussed in this report. The absence of proven experience at this time precludes considering the package incinerator as a reliable, cost-effective method of handling solid waste. Continued evaluation of existing package incinerator facilities, combined with supplementary test and evaluation of combustor performance when processing military solid waste, is required before confident recommendations can be made for implementing such systems to process solid waste generated at Army installations.

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